6.0 UPDATED HYDROLOGIC CONCEPTUAL SITE MODEL

As an initial part of this study, a hydrologic conceptual site model was developed to assess current knowledge of the hydrology of the study area. In order to more fully understand the area's hydrology and the resulting effects on the transport of perchlorate through the environment, several data gaps were identified and prioritized as previously discussed in Chapter 3. Study data collected to fill many of these data gaps were presented in Chapter 5. This chapter summarizes key points from the original conceptual site model and expands the conceptual model based on the new data collected.

6.1 OVERVIEW

NWIRP McGregor straddles the boundary between the Bosque River and Leon River watersheds, which drain into Lake Waco and Lake Belton, respectively. The southerly flows from NWIRP McGregor drain into the Leon River via Station Creek and Onion Creek. The northerly surface water flows originating from the site drain to Lake Waco via several larger streams, including the South Bosque River, Willow Creek, and Harris Creek. Groundwater movement also connects the McGregor site to Lake Waco and Lake Belton.

6.2 HYDROGEOLOGY

Although both shallow and deep aquifers exist in the NWIRP McGregor region, there is no evidence for interaction between them. The deep aquifers in this region are separated by over 900 feet of shale and limestone from the shallow aquifers. Furthermore, the documented recharge zone for the deep aquifers is 70 miles to the northwest. There are no known local faults that would provide conduits for shallow water recharge to the deep aquifers. No perchlorate has been detected in water samples from deep production and private drinking water wells, which suggests there is minimal potential for cross-connection between the shallow water-bearing zone and the deep aquifers (EnSafe, 1999a). Therefore, the deep aquifers will not be discussed further in this report. All further discussions of aquifers in this chapter refer to the shallow aquifer.

6.2.1 Aquifer Properties and Groundwater Chemistry

The shallow, unconfined system is located in fractured limestone and is both heterogeneous and anisotropic on a local level due to weathering, tectonics, changes in lithology, and variations in fracture density. This means that the ability for groundwater to flow can vary both with location in the aquifer and with direction of flow. Therefore, there could be a preferential direction of water movement when considering a limited area of the aquifer. However, because the direction of local anisotropy and heterogeneity can vary significantly over the region, the shallow aquifers can be considered homogeneous on a larger scale, with flow generally following the topography. In other words, contaminated groundwater will tend to flow toward streams under natural conditions much as that described by Cannata (1988). Several values for the properties of the shallow aquifer as determined by previous studies were given in the *Final Conceptual Site Model* (MWH 2002a). These values are summarized in **Table 6-1**.

Table 6-1
Shallow Aquifer Properties

Property	Range	Comments
Matrix Porosity	8%	Howell (1972)
Fracture Porosity	1-2%	Myrick (1989)
Hydraulic Conductivity	10^{-3} m/s to 10^{-10} m/s	Clark (2000) and EnSafe (1999b). Greater near the surface and perhaps near faults and along streams
Lateral Anisotropy	1:1.1 at 10 feet depth, 1:1.73 at 20 feet depth	Increases with depth (Edwards 1991).
Flow Rate	Up to 100 feet per year, possibly higher during strong recharge events.	Yelderman (2002)

The groundwater chemistry is fairly consistent and represents a diffuse flow system. Ionic concentrations in the aquifer fluctuate slightly in response to seasonal changes in the water table. The aquifer properties and groundwater chemistry are described in detail in the *Final Conceptual Site Model* (MWH, 2002a). No additional data were collected during this study to alter the conceptual model of the aquifer properties and chemistry.

6.2.2 Interactions with Surface Flow and Response to Precipitation

Several hydrogeologic data needs were presented in the *Final Conceptual Site Model* (MWH, 2002a). Of these data needs, a better understanding of year-round groundwater/stream interactions and rainfall-runoff relationships were subjected to further study. Two different views regarding the extent of surface-aquifer flow interactions were presented in the *Final Conceptual Site Model* (MWH, 2002a). According to Ensafe, the water table is inconsistent. Flows are altered seasonally, with groundwater contributing to streamflow during the wet season and streams contributing to the groundwater system during drier periods (EnSafe, 1999b). However, according to Dr. Yelderman, there are few times during the year that the streams lose water to the aquifer. The losses that do occur are limited to the uppermost reaches of the streams (Dr. Yelderman, personal communication, February 2002). (Nawrocki, 1996; Myrick, 1989).

Most aquifer recharge was stated to occur from precipitation events during winter and spring when soil moisture is high. Spring is also a likely time for aquifer discharge, as the aquifer becomes saturated due to precipitation. Collins comments that “during the late spring months, the aquifer is characterized by high amplitude water table fluctuations following high intensity, short duration precipitation events” (1989). At this time, water-table levels rise to within a few feet of the surface throughout the drainage basins and the aquifer is described as flooded. Aquifer discharge occurs from numerous small episodic overflow springs and seeps in addition to perennial springs. The upper basins receive more baseflow per basin area because the streams are shallow and the stream dissection is in the most fractured portion of the aquifer material. Groundwater is also lost to evapotranspiration, and much of the evapotranspiration occurs along streams. There is not much evapotranspiration during the winter months while the late summer is usually the driest and hottest time of the year.

As presented in Section 5.1.3, extensive rainfall, stream and groundwater level data were collected to further evaluate the potential for contaminant migration between streams and groundwater. Conclusions from these data were presented for each station in detail in Section 5.1.3.3. The resulting overall conclusions based on these data are presented here, grouped by watershed.

6.2.2.1 Leon River Watershed

The portion of the Leon River watershed potentially affected by runoff from NWIRP McGregor is characterized by monitoring stations on Station Creek, Tributary M, Onion Creek, and the Leon River downstream of Station Creek. Stream level and groundwater level data collected over one year are presented in Section 5.1.3.3. These data allow each station to be characterized as a gaining or losing stream location based on a comparison of the stream level and groundwater level data. With the exception of monitoring station OC1, level data collected generally show the streams to trend from gaining streams in the upper reaches of the watershed to losing streams in the lower reaches. **Table 6-2** summarizes the findings presented in Section 5.1.3.

Streamflows estimated and presented in Section 5.1.4.1 can also be used to characterize the reaches between stations as gaining or losing streams. In the Leon River watershed, calculated flows typically supported the findings based on relative stream and groundwater levels. Based on comparisons in flow between stations, the stream reach from the confluence of Station Creek and Tributary M to monitoring station SC3 may typically be a gaining stream. Flows calculated at monitoring station SC3 were typically higher than the sum of flows at upstream stations SC1 and TRM1. There do not appear to be any other significant tributaries draining to monitoring station SC3. The stream seems to be gaining the most in winter and early spring. However, by late summer all three of these stream locations are dry. The stream reach between upstream stations SC3 and OC1 and downstream station SC5 appears to be a losing stream based on the flow data, except during significant rainfall events. Flows at monitoring station SC5 were lower than those at monitoring stations SC3 or OC1, except during peaks in flow following rainfall events. Monitoring station SC5 was frequently dry, even when streams at upstream stations were flowing.

Table 6-2
Stream Classifications in the Leon River Watershed, Based on Level Data

Monitoring Station	Stream Classification	Comments
SC1	**Gaining** (Intermittent)	GW levels were always higher than stream levels during the data collection period. This is an intermittent stream, indicating that GW levels are not high enough during dry periods to contribute to stream flow.
TRM1	Typically **gaining**, but losing during NWIRP discharge events. Intermittent stream.	GW level was higher than stream level, except during stream level peaks attributed to NWIRP discharges. Peaks in GW level were evident at MW-SC3 during these discharge events, demonstrating a connection between surface water in Tributary M and groundwater during these events.
SC3	**Transitional**; typically gaining during wet weather, losing during late summer and other dry periods	GW level varies from above to below stream level, depending on frequency and duration of rainfall events
OC1	**Losing**	GW levels consistently lower than stream levels.
SC5	**Transitional**; gaining during winter/spring (intermittent), losing during late summer.	GW levels higher than stream levels until late summer, when they fall below the stream level.
LR1	**Losing**, but weak connection.	GW levels always below stream levels. However, the connection between stream and groundwater systems appears weak, as GW levels do not seem to respond appreciably to changes in stream level.

Stream level data, groundwater level data and estimated streamflows suggest a combination of the views presented in the *Final Conceptual Site Model* (MWH, 2002a) existed in this portion of the Leon River watershed during the data collection period. Most upstream stations in this watershed were typically gaining streams, although intermittent. Groundwater may not be high enough at the stream bed during dry periods to contribute to stream flow. Stations farther downstream were transitional depending on the season. Onion Creek at monitoring station OC1 also appears to be a losing stream. The furthest downstream stations were predominantly losing. These data indicate that contaminated groundwater could potentially enter streams in upstream areas of this watershed and move between the streams and groundwater in central regions on Station Creek. However, contaminated water is unlikely to move between the stream and groundwater around monitoring station LR1.

6.2.2.2 Bosque River Watershed

The portion of the Bosque River watershed potentially affected by runoff from NWIRP McGregor is characterized by monitoring stations on Harris Creek, the South Bosque River, and the Middle Bosque River downstream of the South Bosque River. Stream level and groundwater level data collected over one year are presented in Section 5.1.3.3. These data allow each station to be characterized as a gaining or losing stream location based on a comparison of the stream level and groundwater level data. Due to lack of groundwater data at some stations in this watershed, the Bosque River watershed stations can not be as thoroughly characterized as the Leon River watershed stations were. Monitoring stations in this watershed did not exhibit a trend from gaining to transitional to losing streams as clearly as the Leon River watershed stations. **Table 6-3** summarizes the findings presented in Section 5.1.3.

Table 6-3
Stream Classifications in the Bosque River Watershed, Based on Level Data

Monitoring Station	Stream Classification	Comments
HC1	Transitional	GW levels variable relative to stream level, with GW levels typically higher than stream level in winter/early spring, and stream level higher than GW level in late spring and summer.
HC2	Unknown	Stream level higher than GW level, but the monitoring well is in a bad location and may not be representative (as discussed in Section 5.1.3)
SBR3	Gaining	GW levels consistently higher than stream levels.
SBR1	Gaining	GW levels consistently higher than stream levels.
SBR2	Losing	GW levels typically lower or only slightly higher than stream levels
SBR4	Unknown	No monitoring well at this location.
SBR5	Gaining	GW levels typically higher than stream levels.
MBR1	Unknown	No monitoring well at this location.

Streamflows estimated and presented in Section 5.1.4.1 may also be used to some extent to characterize the reaches between stations. Additional tributaries exist between each monitoring station on Harris Creek and the South Bosque River. Therefore, an increase in streamflow from upstream to downstream does not necessarily mean the stream is a gaining stream in the sense used during this study (i.e., gaining water from groundwater). However, if streamflow decreases from upstream to downstream, that does indicate that the stream reach may be a losing stream. Streamflow calculations for stations on the Harris Creek branch (HC1, HC2, and SBR3) indicate that the stream reach between monitoring stations HC1 and HC2 was a losing stream during the summer months.

During other times of the year, streamflows increased somewhat from upstream stations to downstream stations. Stations on the South Bosque branch (SBR1, SBR2, and SBR4) likewise suggested that the reach between SBR1 and SBR2 could be a losing stream during the summer months.

Stream level data, groundwater level data and estimated streamflows suggest that there is the potential in the Bosque River watershed for contaminated groundwater to enter streams and vice versa. Despite the characterization of these streams as losing streams in some areas, observations do not contradict Yelderman's estimate that 40-60% of the baseflow in the upper portions of this watershed is from groundwater (Dr. Joe Yelderman, personal communication, August 1999). Unlike the upper portions of the Leon River watershed, streams in the Bosque watershed never went dry even during extended periods with limited rainfall.

6.3 LAKE ATTRIBUTES

This summary of the attributes of Lake Waco of the Bosque River watershed and Lake Belton of the Leon River watershed is based on published and technical report data and on the personal observations of Dr. Lind. The principal attributes of Lakes Waco and Belton that are relevant to the fate and transport of river-borne materials are discussed briefly in the subsections below. More detailed information can be found in the *Final Conceptual Site Model* (MWH, 2002a). This section also expands the conceptual model of Lake Belton based on data collected during the ADCP study discussed in Chapter 5.

6.3.1 Lake Waco

The Bosque River watershed drains to Lake Waco, with potentially contaminated surface drainage from NWIRP McGregor travelling via Harris Creek and the South Bosque River to the Middle Bosque River and finally into Lake Waco. Other streams draining into Lake Waco include Hog Creek and the North Bosque River. The North Bosque River, which does not receive any runoff from NWIRP, contributes the majority of inflow to Lake Waco, approximately 80% on average (Dr. Owen Lind, personal communication). The principal attributes of Lake Waco relevant to the fate and transport of river-borne materials include: mixing patterns, flushing rate, water transparency, lake morphometry, and trophic state.

Lake Waco is a moderately eutrophic lake with a reservoir volume of 144,830 AF. During development of the CSM, the normal pool elevation of Lake Waco was 455.0 feet above mean sea level (TWDB, 1994). At this pool elevation, Lake Waco did not develop persistent density (thermal) stratification (Kimmel and Lind, 1972); wind mixing assured both horizontal and vertical mixing of dissolved and suspended materials. However, the USACE and the City of Waco recently completed a pool raising project in Lake Waco that increased the normal pool elevation by seven (7) feet. Although there is no evidence so far of significant changes to this lake as a result of the pool raising project, there is a possibility that the greater depth could allow Lake Waco to stratify. The City of Waco has been conducting an on-going limnological study of this lake, and more data will become available as a result of their work.

Strong wave action is common in Lake Waco and causes shoreline erosion. This wave action re-suspends clays and contributes to turbidity. There is also an aeration system located near the dam that further contributes to vertical mixing in the lake.

Mean multi-year flushing time is one year. (Kimmel and Lind, 1972; Rendon-Lopez, 1997). However, because of the great climatic variability of the region, water retention time is highly variable among years with a range of approximately 0.1 to 5 years. (McFarland et al., 2001). The longer the water retention time, the more opportunity for biological uptake of contaminants. Thus, under high flushing conditions any material entering the reservoir has much less probability of biological uptake than under normal flushing rates.

The warm temperature of the bottom of Lake Waco results in high deep-water bacteria metabolism. Assuming traditional temperature-metabolism coefficients, the metabolic rate would be approximately double that of Lake Belton's deep bacteria (Atlas and Bartha, 1998). Dissolved oxygen solubility in water is a function of temperature: the higher the temperature, the lower the solubility. At 25 degrees Celsius the maximum oxygen is approximately 8 mg/L (ppm) whereas at 15 degrees Celsius it is almost 10 mg/L (Lind, 1985). Because of this low initial solubility and the relatively high content of dissolved organic matter, dissolved oxygen diminishes with depth, even though the Lake is well-mixed. The concentration rarely reaches zero, but does so briefly in scattered depressions (McFarland et al., 2001).

6.3.2 Lake Belton

The Leon River watershed drains to Lake Belton, with potentially contaminated surface drainage from NWIRP McGregor travelling via Station Creek to the Leon River and finally into Lake Belton. Cowhouse Creek also drains into Lake Belton, but the Leon River is Lake Belton’s principal source of water.

Lake Belton lies in a long (approximately 21-mi.), narrow and tortuous valley in a generally southerly flowing segment of the Leon River (Lind, 1976), has a volume of 434,500 acre-feet (AF) and has a normal pool elevation of 594.0 feet above mean sea level (TWDB, 1994). The trophic state of Lake Belton may be classified variously because of its length. It experiences one period of top to bottom mixing and one period of density stratification each year (Hutchinson, 1957). The reservoir's morphometry and alignment to the prevailing winds enable the long period of stratification (Lind, 1982). The down-reservoir deeper portion is aligned perpendicular to the prevailing westerly winds. It is situated in a relatively deep valley that provides shelter. The maximum fetch to northwesterly winds is only about 3 mi. The top of the hypolimnion for much of the stratification period is approximately 18-m. The lower 8 to 10 miles of reservoir are of sufficient depth to stratify. Significant portions of the lake of lesser depth are not stratified (Cowhouse arm and upper Leon River arm).

Mean multi-year water retention time is 1.9 years. However, because of the great climatic variability of the region, water retention time is highly variable among years with a range of approximately 0.5 to 6.3 years. The longer the water retention time the more opportunity for biological uptake of contaminants. Thus, under high flushing conditions, any material entering the reservoir has much less probability of biological uptake than under normal flushing rates.

The dissolved oxygen concentration diminishes rapidly with depth (Lind et al., 2002), reaches zero throughout the lowest layer of the lake by the first part of July and remains so until autumnal mixing, typically during mid November. This stratification is significant, as anaerobic bacteria present in Lake Belton were demonstrated during this study to have the ability to reduce perchlorate to more innocuous species (see Section 5.2.2).

There is evidence of unusual properties of the hypolimnion anaerobic bacterial community of Lake Belton (Rutherford, 1998; Lind et al, 2002; Christian et al., 2002). For most lakes, the abundance and individual cell volumes of bacteria are inversely correlated with oxygen; i.e., anoxia results in more and larger bacteria. For Lake Belton, this is not so. For the hypolimnion near the dam, there was no correlation of either abundance or volume with oxygen concentration. For the hypolimnion near the upper reservoir limits of stratification, the correlation was strongly direct. It has been postulated that this may be the result of different types of organic matter to promote bacterial production.

One data gap identified in the *Final Conceptual Site Model* (MWH, 2002a) was whether preferential flow paths exist in Lake Belton. Based on seasonal ADCP surveys conducted during this study (Section 5.1.4.2), consistent preferential flow and current profiles were not identified. Therefore, thalweg flow does not appear to be consistently present. There also appeared to be no preferential flow toward water intakes.

6.4 WATER BUDGETS

In order to assess the fate and transport of perchlorate in the study area, the volumes of water moving through the surface water and groundwater system from NWIRP McGregor to the lakes needs to be better understood. A water budget, a quantification of inflows and outflows in a watershed, was presented for both Lake Belton and for Lake Waco in the *Final Conceptual Site Model* (MWH, 2002a). These water budgets were described from the perspective of the lakes as inflows, outflows, and changes in lake storage based on data collected by the USACE. Inflows consist of stream inflow, groundwater inflow via seeps and springs, precipitation falling directly on the lake, and discharges of treated effluent into the lakes. Outflows include municipal pumping, dam releases, evapotranspiration and groundwater outflow. If the amount of water stored in each lake does not change (as indicated by the water elevation), inflows should be approximately equal to outflows. If lake storage changes, inflows would not equal outflows for that period of record. This section compares streamflows estimated during this study, as presented in Section 5.1.4.1, to estimated inflows into the lakes to assess the potential volume of water reaching the lakes from NWIRP McGregor.

6.4.1 Leon River Watershed

Runoff from NWIRP McGregor could reach Lake Belton via flows from Tributary M, Onion Creek, and Station Creek discharging into the Leon River, which supplies most of the inflow into Lake Belton.

An analysis of many years of USACE data was presented in the *Final Conceptual Site Model* (MWH, 2002a). These data indicated typically higher inflows from early spring until mid-summer and lower flows during the rest of the year, with extended periods of higher inflows during years with higher than normal rainfall. The average daily inflow (including inflow from all sources) into Lake Belton was calculated to be approximately 690 cfs, with a peak of 81,300 cfs and minimums near zero cfs.

The *Final Conceptual Site Model* (MWH, 2002a) also presented annual water budgets from 1994 to 1999, calculated based on the USACE data. The minimum inflow into Lake Belton during that period was approximately 148,100 AF, and the maximum inflow was estimated to be 1,649,600 AF. Inflow into Lake Belton from October 17, 2002 through October 2, 2003 based on preliminary USACE data was estimated to be approximately 248,000 AF, closer to the minimum inflow observed between 1994 and 1999 than to the maximum inflow. **Table 6-4** presents total flow estimated at each of the Leon River watershed stations during this same period.

Table 6-4
Total Estimated Streamflow at Leon River Watershed Stations
October 17, 2002 through October 2, 2003

Monitoring Station	Total flow (Acre-Feet)	Peak Daily Flow (cfs)	Percentage of Total Inflow into Lake Belton	Percentage of Peak Daily Inflow into Lake Belton
SC1	1,260	30	0.5 %	0.5%
TRM1	1,370	10	0.6%	0.2%
SC3	7,490	60	3.0%	0.9%
OC1	4,370	55	1.8%	0.8%
SC5	1,220	100	0.5%	1.5%
LR1	224,000	1,780	90%	27%
(Lake Belton)	248,000	6,500	100%	100%

The total and peak daily flows at each of the stations upstream of LR1 demonstrate that drainage from NWIRP McGregor makes up a very small percentage of inflow into Lake Belton. The Leon River, however, seems to make up most of the inflow into Lake Belton under average conditions, as 90% of the total inflow into Lake Belton during this period was estimated to come from the Leon River. This observation supports the assumption stated previously in Section 6.3.2 that the Leon River provides most of the inflow into Lake Belton. Despite the high percentage of total flow entering Lake Belton from the Leon River, monitoring station LR1 showed a much lower peak daily flow than the peak flow reported entering Lake Belton. This difference between the high percentage of total inflow versus the moderate percentage of peak daily inflow suggests that there may be several intermittent streams draining to Lake Belton.

6.4.2 Bosque River Watershed

Runoff from NWIRP McGregor could reach Lake Waco via flows from Harris Creek and the South Bosque River, which discharge into the Middle Bosque River. The Middle Bosque River supplies a portion of the inflow into Lake Waco.

An analysis of many years of USACE data was presented in the *Final Conceptual Site Model* (MWH, 2002a). These data indicated typically higher inflows from early spring until mid-summer and lower flows during the rest of the year, with extended periods of higher inflows during years with higher than normal rainfall. The average daily inflow (including inflow from all sources) into Lake Waco was calculated to be approximately 490 cfs, with a peak daily inflow of 134,400 cfs and minimums near zero cfs.

The *Final Conceptual Site Model* (MWH, 2002a) also presented annual water budgets from 1994 to 1999, calculated based on the USACE data. The minimum annual inflow into Lake Waco during that period was approximately 71,700 AF, and the maximum annual inflow was estimated to be 961,000 AF. Inflow into Lake Waco from October 17, 2002 through October 2, 2003 based on preliminary USACE data was estimated to be approximately 227,000 AF, closer to the minimum inflow observed between 1994 and 1999 than to the maximum inflow. **Table 6-5** presents total flow estimated at each of the Bosque River watershed stations between October 17, 2002 and May 20, 2003, because the data sets at monitoring SBR3 and SBR4 were incomplete. Flow for the entire period from October 17, 2002 through October 2, 2003 are included in parentheses, where available.

Table 6-5
Total Estimated Streamflow at Bosque River Watershed Stations
October 17, 2002 through May 20, 2003

Monitoring Station	Total flow (Acre-Feet)*	Peak Daily Flow (cfs)	Percentage of Total Inflow into Lake Waco*	Percentage of Peak Daily Inflow into Lake Waco
HC1	4,540 (6,190)	65	2.5% (2.7%)	1.9%
HC2	6,280 (6,890)	75	3.5% (3.0%)	2.2%
SBR3	9,960	160	5.5%	4.8%
SBR1	3,460 (4,470)	550	1.9% (2.0%)	17%
SBR2	23,400 (23,500)	450	13% (10%)	14%
SBR4	19,500	920	11%	28%
(Lake Waco)	182,000 (227,000)	3,340	100% (100%)	100% (100%)

* Values in parentheses are for the period from October 17, 2002 through October 2, 2003

Based on these data, drainage from Harris Creek and the South Bosque River could make up approximately 15% of the inflow into Lake Waco on average and approximately 35% of the daily inflow during peak flow conditions. The majority of inflow (approximately 80%) into Lake Waco is thought to come from the North Bosque River, which does not receive any surface runoff from NWIRP.

6.5 MIGRATION PATHWAY ANALYSIS

The hydrologic model and water budget results suggest that significant dilution should occur before perchlorate contamination reaches the lakes. With the exception of a single surface water detection in Lake Waco, two detections in Lake Belton, and two detections downstream of Lake Belton, historical perchlorate data collected by the U.S. Navy support this supposition.

This section adds to information presented in the *Final Conceptual Site Model* (MWH, 2002a) to discuss results from the extensive perchlorate sampling completed during this study. This new information is integrated with the updated hydrological conceptual model and perchlorate fate and transport characteristics to assess potential migration pathways between perchlorate sources and Lakes Belton and Waco.

6.5.1 Nature and Extent of Contamination

Extensive stream water, lake water, and pore water sampling was completed during this study, as described in Chapter 5. Sampling from the lakes included the following:

- Delta area grid sampling of surface water (22 samples from each lake)
- Delta area grid sampling of pore water (63 samples from Lake Belton, 65 samples from Lake Waco)
- Potable water intake sampling (77 samples)
- Irrigation water intake sampling (41 samples)
- Sampling on each ADCP transect, above and below the thermocline (83 samples total)
- Sampling on ADCP transects for preferential flows (22 samples total)

Analytical results for all of the lake samples listed above were below the MDL (1 μg/L) for perchlorate.

Sampling from streams that potentially contain runoff from the NWIRP property included the following:

- Grab sampling from various points on the streams
- Bi-weekly automated sampling from the 15 monitoring stations (typically 35-55 samples per station)
- Automated sampling during two storm events (typically around 100 samples per station per storm)
- Stream pore water sampling

Table 6-6 lists summary statistics for each site from the bi-weekly automated sampling results.

Table 6-6
Summary Results for Automated Stream Sampling

Monitoring Station	Average Perchlorate Concentration* (µg/L)	Maximum Perchlorate Concentration (µg/L)	Maximum Perchlorate Concentration During a Storm Event (µg/L)
Leon River Watershed:			
TRM1	10.1	111	3.0
SC1	ND	ND	ND
SC3	5.11	38	11
OC1	0.56	3.0	ND
SC5	2.73	7.6	No samples collected; site dry
LR1	ND	ND	ND
Bosque River Watershed:			
HC1	1.81	6.5	2.0
HC2	1.25	4.8	2.0
SBR3	0.88	2.0	ND
SBR1	2.73	4.7	4.0
SBR2	1.51	3.0	2.0
SBR4	1.10	3.0	1.0
SBR5	0.81	2.0	2.0
MBR1	ND	ND	ND
Cowhouse Creek:			
CHC1	ND	ND	ND

* Averages from bi-weekly automated sampling. These averages do not include storm samples.
ND = < 1µg/L

As seen on **Table 6-6**, perchlorate concentrations decreased moving from upstream at monitoring station TRM1 on Tributary M downstream to monitoring station LR1 on the Leon River. Likewise, perchlorate concentrations detected along Harris Creek and the South Bosque River also decreased moving downstream. Neither monitoring station LR1 on the Leon River nor monitoring station MBR1 on the Middle Bosque River, both of which discharge directly into Lake Belton and Lake Waco, respectively, had any samples with detectable perchlorate concentrations.

Prior to sampling, storm events were thought to potentially cause more perchlorate contamination to reach the lakes, due to first flush effects. However, the stream sampling conducted during two storm events discounted this theory at most stations. As seen on the data plots from the first storm event, included in **Appendix F**, monitoring stations SBR1 and SC3 were the only two stations where a first-flushing effect was observed, evidenced by a small spike in perchlorate concentrations following the storm. However, perchlorate concentrations were then diluted rapidly due to increased flow. No other monitoring stations showed a first flush effect, but some uncertainty on possible first-flush effects remains. The two storm events sampled during the study were not the largest storms that occurred during the study period. Monitoring station SC3 was the only station with a perchlorate concentration above the RL (4 μg/L) during a storm event.

6.5.2 Primary Migration Pathways

Because NWIRP McGregor is located on a ridge separating the Bosque and Leon River watersheds, releases of perchlorate from the facility disperse in two main directions, primarily in surface water and groundwater. Harris Creek and the South Bosque River transfer water northeast to the Middle Bosque River and finally to Lake Waco. Station Creek transports water south to the Leon River and finally to Lake Belton. The major inflow source of water to the watersheds is precipitation.

As discussed in Section 6.2.2**,** several of the streams studied apparently transition between gaining and losing streams, allowing the chance for contaminant migration from groundwater to surface water and vice versa. Additionally, groundwater is thought to make up a significant percentage of the baseflow in the upper portions of the streams in the Bosque River watershed.

Initial analysis presented in the *Final Conceptual Site Model* (MWH, 2002a) suggested that significant dilution should occur before perchlorate contamination reaches the lakes. The extensive stream and lake sampling conducted during this study supported this initial assessment and further demonstrated that significant dilution occurs by the time perchlorate contamination reaches the Leon and the Middle Bosque Rivers. Estimates of the perchlorate concentration necessary to potentially cause a detection at or above the RL (4 μg/L) in one of the lakes are presented in **Table 6-7**.

These estimates are based on the percentage of total lake inflow at each of the monitoring stations presented in Section 6.4. This approach assumes that all of the flow at any particular station eventually reaches the lake and assumes that the lake inflow is well-mixed.

The concentrations listed for average lake inflow are the concentrations required at that station to result in a concentration in the lake inflow at the RL, based on nearly one year of station flow data and lake inflow data. To achieve a sustained perchlorate concentration at the RL in the lake during this year, the concentration at a particular station would need to average the value presented in this table. A spike in concentration to these levels may cause a spike up to the RL in the lake inflow, but would quickly be diluted by less contaminated water. Actual average perchlorate concentrations detected at the Leon River watershed stations during this period ranged from 0.1% to approximately 11% of these values. The 11% is based on assuming a value of 0.5 μg/L, half of the MDL (1 μg/L), at station LR1, as there were no detections at this station. Not including this station, percentages ranged up to approximately 2% of these values. Actual average perchlorate concentrations detected at the Bosque River watershed stations ranged from approximately 0.8% to 4% of these values.

Concentrations listed under peak day inflow are the concentrations that would have been required under peak flow conditions (storm events) to result in a peak concentration in the lake inflow at the RL during the monitoring period. Again, a spike in the perchlorate concentration to these levels would have resulted in a spike in the lake inflow concentration to the RL, but if station concentrations subsequently decreased, that spike in the inflow concentration would quickly be diluted. Actual concentrations measured during storm events ranged from 0.1% to approximately 17% of these values.

Table 6-7
Estimated Perchlorate Concentrations Necessary to Cause a Detection at the RL (4 µg/L) in the Lakes

Monitoring Station	Percentage of Total Lake Inflow	Percentage of Peak Daily Lake Inflow	Perchlorate Conc. To Reach RL in Lake Inflow (Average Inflow) µg/L	Perchlorate Conc. To Reach RL in Lake Inflow (Peak Day Inflow) µg/L
Leon River Watershed				
SC1	0.5%	0.5%	800	800
TRM1	0.6%	0.2%	670	2000
SC3	3.0%	0.9%	130	440
OC1	1.8%	0.8%	220	500
SC5	0.5%	1.5%	800	270
LR1	90%	27%	4.4	15
Bosque River Watershed				
HC1	2.7%	1.9%	150	210
HC2	3.5%	2.2%	110	180
SBR3	5.5%	4.8%	73	83
SBR1	2.0%	17%	200	24
SBR2	13%	14%	31	29
SBR4	11%	28%	36	14
SBR3 + SBR4	17%	33%	24	12